

Extended Abstract

RETENTION BASINS TO MINIMIZE STORMWATER RUNOFF IN URBAN AREAS

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Keywords: Urban development; Urban drainage; Stormwater runoff; Receiving Water Bodies; Low Impact Development techniques (LID); Computational model SUSTAIN.

1 INTRODUCTION

In cities around the world, urban population is still rising and expected to reach 69% in 2050 (United Nations Population Division, 2010). This rapid and uncontrolled urban development can dramatically alter the hydrologic cycle of an entire watershed. Prior to development, native vegetation can either directly intercept precipitation or evapotranspire that portion that has infiltrated into the ground back into the atmosphere. Urbanization can modify this situation, replacing grassland and forests by the impervious surfaces of streets, driveways and buildings, greatly intensifying stormwater runoff and minimizing groundwater recharge. In addition, urban runoff was found to be a significant source of pollution entering the receiving water bodies.

Classic systems of urban drainage have focused on collecting and conveying the runoff from the entire site through a structural conveyance system to a centralized facility or to water bodies (Ferreira, 1999). However, these solutions have become ineffective as impervious areas increased. This has led to the advent of alternative solutions for urban drainage called Low Impact Development techniques (LID). These solutions seek to reduce and/or prevent adverse runoff impacts, managing stormwater as close to its source as possible. To achieve this, LID solutions include both non-structural and structural techniques called Best Management Practices (USEPA, 2015).

The U.S Environmental Protection Agency (EPA), has been working since 2003 to develop a decision-support system in order to help users to implement structural BMPs that result in the most cost-effective, achievable and practical strategy for the location of interest. The resulting modeling framework is called SUSTAIN- System for Urban Stormwater Treatment and Analysis Integration. This software uses simulation techniques (from SWMM and HSPF) with Geographic Information Systems (GIS), to enable users developing sustainable drainage solutions that meet water quantity and quality goals (USEPA, 2009).

This study will analyse the contribution of SUSTAIN as a decision support tool to solve problems of modern urban drainage. This software will be applied to an urban watershed called Fala-Espadaneira located in Coimbra (Portugal), which currently presents serious problems in stormwater drainage system, caused by urban development (ÁGUAS DE COIMBRA, 2009). The applied methodology aims to create a virtual stormwater drainage network model in order to evaluate both the current and future scenarios for this watershed. A combination of structural BMPs will be implemented in the model in order to solve/mitigate the problems identified for this catchment.

Thus, the goal of this study is to present alternative solutions to the classical approach of urban drainage, which typically consists in increasing the capacity of stormwater drainage network, in order to solve/mitigate the problems identified in Fala-Espadaneira basin. These solutions will be obtained through SUSTAIN software, and will be chosen through cost-effectiveness criteria.

2 STUDY AREA AND PROBLEM FORMULATION

2.1 Fala-Espadaneira basin

Fala-Espadaneira watershed is located in Coimbra (figure 1), in the parish of São Martinho do Bispo and has an area of 3.8 km² (ÁGUAS DE COIMBRA, 2009). This basin is located between Antanho basin (also known as Ribeira de Frades) and Ribeira dos Covões basin.

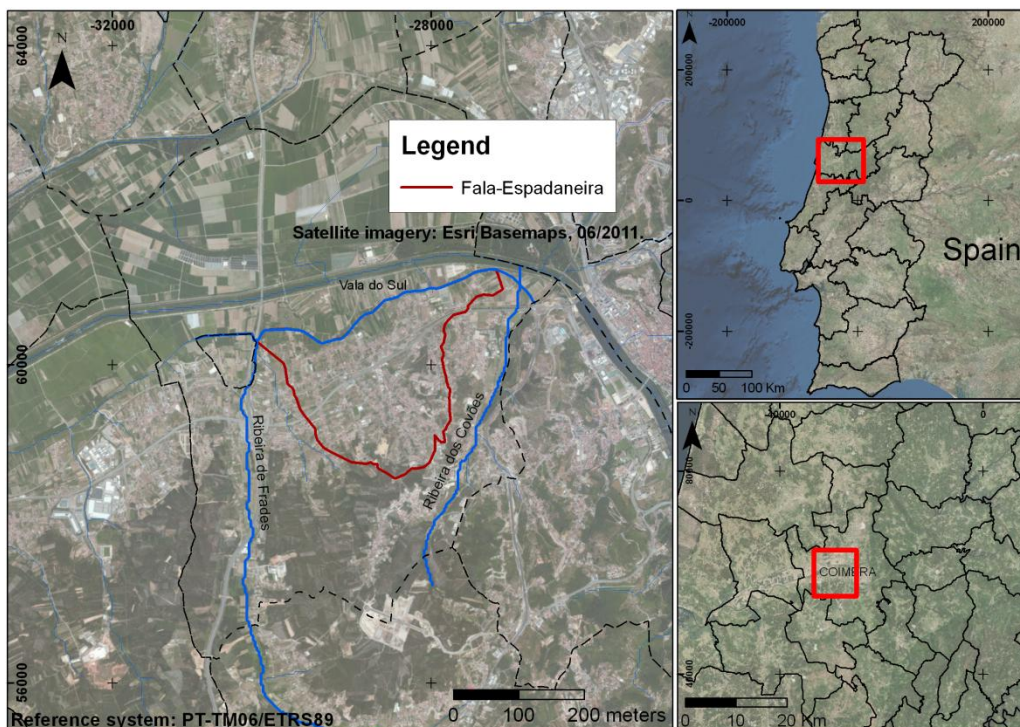


Figure 1- Location of Fala-Espadaneira basin.

This basin is served by a Separate Sewer System, which includes a 36.0 Km network of wastewater drainage systems and a 7.3 km of stormwater drainage network (ÁGUAS DE COIMBRA, 2009). Stormwater runoff produced in this basin is then conveyed to Vala do Sul, through water lines flowing into this stream (figure 2a).

Currently, urban development in Fala-Espadaneira basin led to an increase of impervious surfaces (buildings, paved lots, roads, etc) and channeling of watercourses, thereby causing severe and frequent flooding problems in this catchment.

As can be seen in figure 2b, Fala-Espadaneira basin is divided into 5 different zones. Given the fact that this basin has large dimensions, it was decided to begin this study with zone 1, so all the information presented in this paper is regarding only this area. It was decided in this study to begin the analysis with zone 1 because this area is not influenced by stormwater runoff generated in upstream zones (with the exception of

stormwater runoff produced in Ribeira dos Covões basin which is conveyed to Fala-Espadaneira basin through Vala do Sul stream).

It should be further noted that the present study will be conducted through the analysis of stormwater runoff flowing into 5 control sections, as shown in figure 2c.

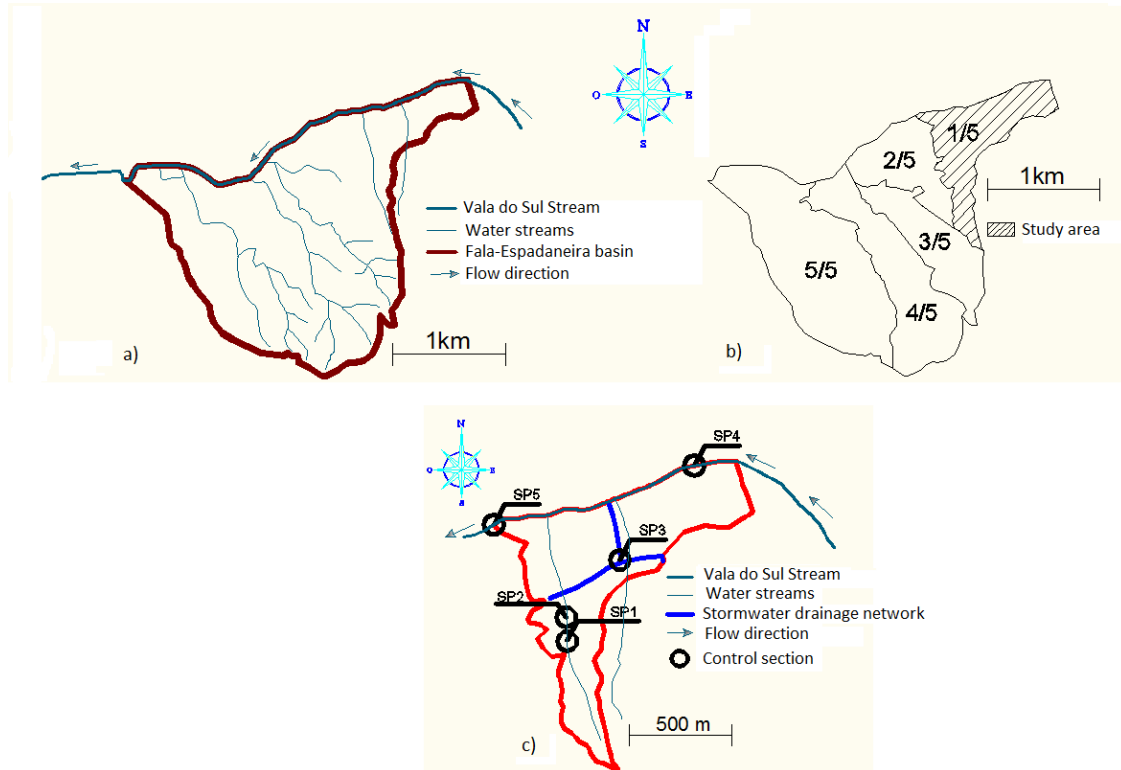


Figure 2- a) Representation of natural water streams and Vala do Sul stream; b) Schematic representation of the study area (zone 1); c) Study area with emphasis on the 5 control sections (adapted from Fala-Espadaneira Drainage Master Plan).

2.2 Current and future scenarios

The results presented in table 1 were taken from Fala-Espadaneira Drainage Master Plan (FEDMP), provided by AC, ÁGUAS DE COIMBRA, E. M. company, and illustrate the current and future scenarios, corresponding, respectively, to years 2006 and 2046.

Table 1 - Peak discharge for each control section regarding current and future scenarios (T=20 years). Taken from (ÁGUAS DE COIMBRA, 2009).

Control section	Peak discharge (m ³ /s)		Section capacity (m ³ /s)
	2006	2046	
SP1	2.01	2.01	0.80
SP2	2.01	2.08	0.77
SP3	0.60	0.65	1.01
SP4	16.80	21.27	7.83
SP5	16.80	21.27	6.68

As one can see, the current situation in this catchment is very serious, with only one section able to drain the peak discharge estimated for T=20 years. However this situation is likely to get worse, with increase of new impervious surfaces.

3 STORMWATER MODEL SETUP

3.1 Creating spatial data

3.1.1 Drainage areas and Digital Elevation Model (DEM)

The Digital Elevation Model is presented in Figure 3, with a grid cells resolution of 0.5 m. The highest areas are in the south part of zone 1 with elevation points higher than 80 meters above sea level.

SUSTAIN allows users to automatically delineate drainage areas using DEM raster layer. However, the subcatchments used in this study are those which are presented in Fala-Espadaneira Drainage Master Plan (figure 4).

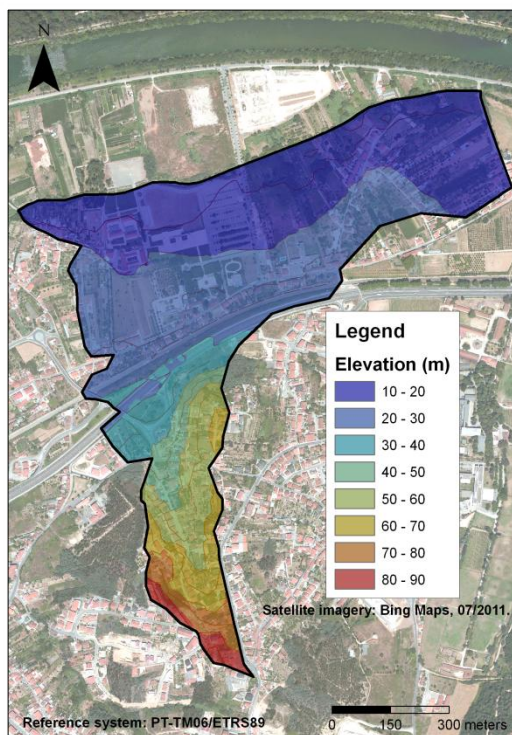


Figure 3 – Digital Elevation Model.

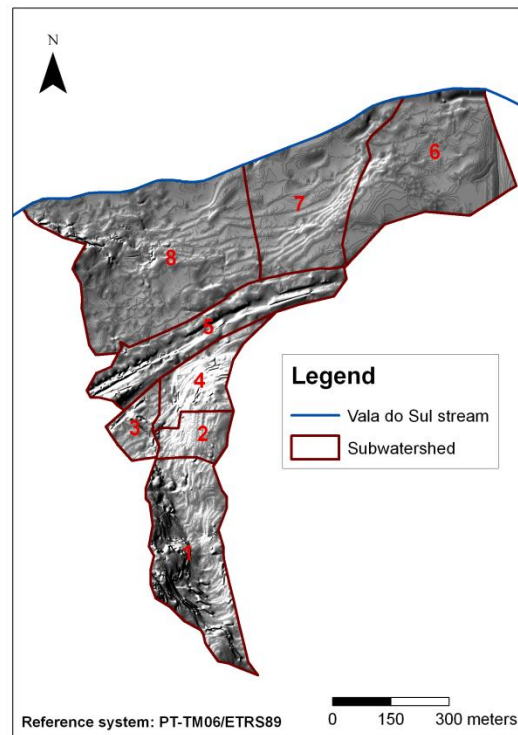


Figure 4 – Study area subdivided into Subwatersheds.

3.1.2 Urban Land Use mapping scheme

The Land Use data file was prepared in ArcGIS shapefile format using relatively recent Bing Maps aerial imagery, from July 2011. This satellite imagery was used to define the boundaries of several urban elements. For this reason the current scenario of this study is the year 2011.

Four land cover classes (Buildings; Roadways; Parking Lots and Streets) were identified, and their boundaries digitized on screen using the Editing tools of ArcGIS (figure 5). These urban elements will be used later to calculate the percent impervious coverage of the study area.

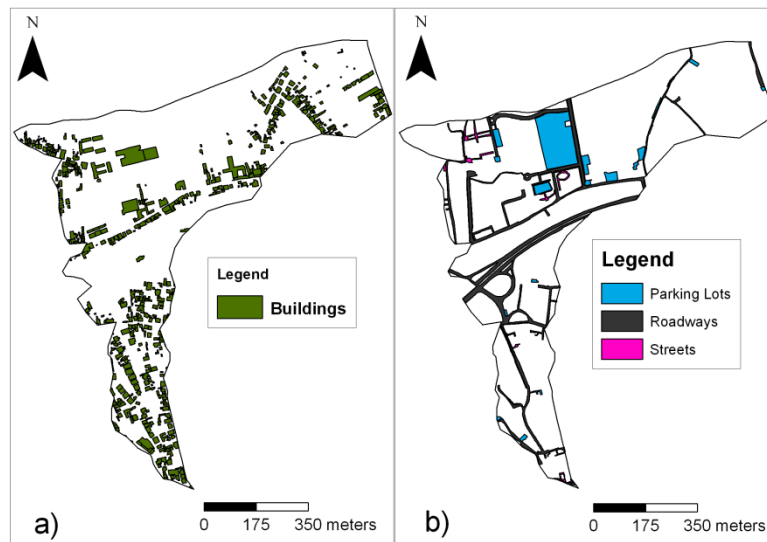


Figure 5 – Urban Land Use representation: a) Buildings; b) Parking Lots, Roadways and Streets.

3.1.3 Impervious surfaces mapping scheme

Impervious surface mapping was produced considering that Buildings, Roadways, Parking Lots and Streets were impervious surfaces (imperviousness degree 100%). The high resolution ortofoto used in this study (from July 2011) has allowed identifying the existence of two parking lots and one road made of porous pavements, which were considered to have an imperviousness degree of 50%. Pervious soil was obtained by subtracting all the above elements from Zone 1, which was accomplished using ArcGIS spatial tools.

Imperviousness degree for future scenario (2051) was obtained using runoff coefficient (from current and future scenarios) presented in Fala-Espadaneira Drainage Master Plan.

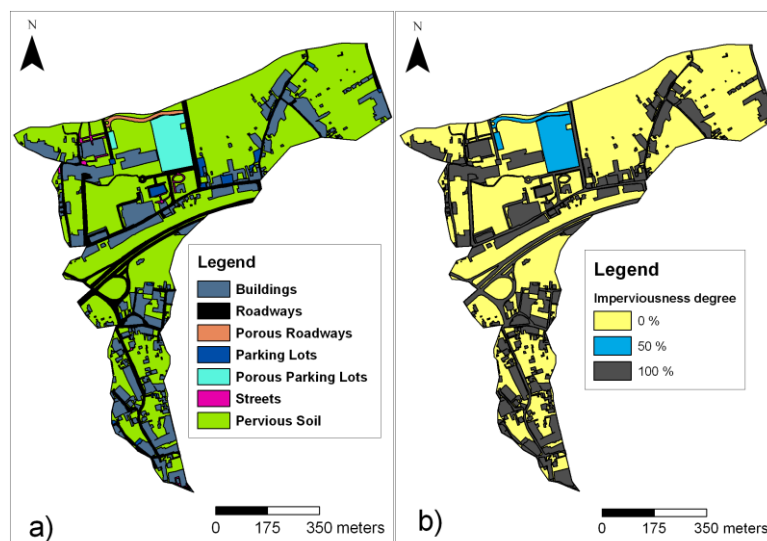


Figure 6 – a) Impervious/pervious surface pattern; b) Imperviousness degree.

3.2 Subwatershed Characteristics

Surface runoff is a complex and dynamic process, especially in the context of spatial variability. The reason for this is that Subwatersheds characteristics are difficult to

quantify, since it can vary widely not only in space (from one place to another), but also over time (depending on the time of the year). A geographical Information System application in small grid cells is, therefore, very useful to consider the special behavior of variables associated to the origin of surface runoff (Beskow et al., 2009).

In order to reduce spatial and temporal variability, subcatchments are represented mathematically as spatially lumped, nonlinear reservoirs, and their outflows are routed via channel/pipe. Subcatchments are subdivided into three subareas, impervious area with and without depression storage, and pervious areas with depression storage.

The parameters needed to generate surface runoff are as follows: (i) Area; (ii) Slope; (iii) Saturated hydraulic conductivity (K_s); (iv) Suction head (Ψ_f); (v) Porosity fraction ($\theta_s - \theta_i$); (vi) Manning's overland flow for pervious surfaces (n_p) and impervious surfaces (n_i); (vii) Depression storage for pervious surfaces (DP) and impervious surfaces (DI); (viii) Percentage of impervious surface. The parameters arbitrated for each subwatershed are presented in the following table.

Table 2 – Subwatershed characteristics.

	Subwatershed							
	1	2	3	4	5	6	7	8
Area (m ²)	87743.3	19667.5	16532.0	32409.9	64749.5	111158.2	94947.6	174901.7
Slope (%)	19.5	14.9	12.4	20.0	12.8	3.8	4.4	5.2
K_s (mm/h)	59.8	59.8	59.8	59.8	59.8	59.8	59.8	59.8
Ψ_f (mm)	61.3	61.3	61.3	61.3	61.3	61.3	61.3	61.3
$\theta_s - \theta_i$ (-)	0.382	0.382	0.382	0.382	0.382	0.382	0.382	0.382
$n_p(ft^{-1/3}.s)$	0.40	0.40	0.40	0.40	0.40	0.17	0.17	0.40
$n_i(ft^{-1/3}.s)$	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012
DP (cm)	0.762	0.762	0.762	0.762	0.762	0.762	0.762	0.762
DI (cm)	0.254	0.254	0.254	0.254	0.254	0.254	0.254	0.254
Impervious area (%) - 2011	51.58	72.82	28.32	26.26	41.54	24.58	19.93	38.23
Impervious area (%) - 2051	51.58	72.82	31.59	35.01	44.82	29.31	22.32	42.05

3.3 Ribeira dos Covões basin

As indicated above, stormwater runoff produced in Ribeira dos Covões basin is then conveyed to Fala-Espadaneira basin through Vala do Sul stream. For this reason this basin has to be included in stormwater drainage model.

Data from Ribeira dos Covões basin (subwatershed 9 in the model) has been provided by AC, ÁGUAS DE COIMBRA, E. M. company, and are the following: (i) 3.7% slope; 34.5% of impervious surfaces for current situation and a total area of 660 hectares.

3.4 Weather data

The land simulation module of SUSTAIN uses the daily air temperature, evaporation, and wind speed data from the user-specified climate file. These data were extracted from SNIRH (Water Resources Information System). In order to generate Stormwater runoff, precipitation data set is a necessary input for the land simulation module. The

design storm hyetograph used in this study was the one proposed by Matos (2003), with a 20 year return period (figure 7).

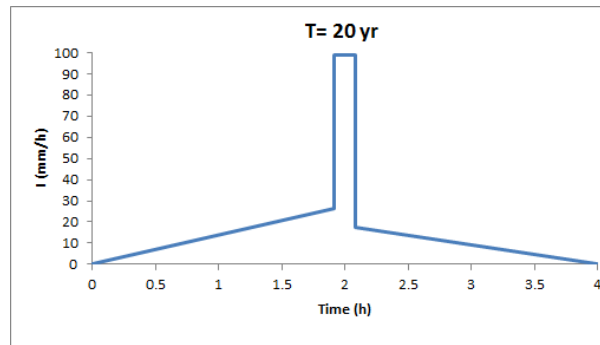


Figure 7 – Design storm hyetograph.

3.5 Stormwater drainage network

3.5.1 Overland flow

Overland flow is generated from each subarea by approximating them as nonlinear reservoirs. This nonlinear reservoir is established by combining the continuity equation with Manning's equation. Infiltration from pervious areas were computed by Green-Ampt equation.

3.5.2 Pipe routing

Pipe routing was computed using “dummy conduits” which means the link has no physical data associated with it, so the inflow is equal to the outflow. Kinematic Wave was used for routing flows through the drainage system. This is an efficient but simplified approach that cannot deal with such phenomena as backwater effects and pressurized flow.

The stormwater drainage network model created in SUSTAIN can be seen in figure 8.

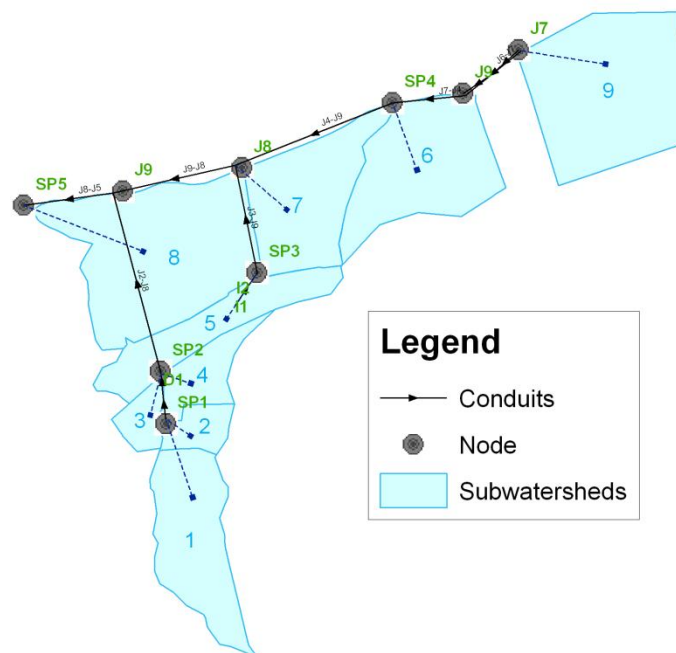


Figure 8 – Stormwater drainage network model created in SUSTAIN.

3.6 Results obtained for current and future scenarios

The results obtained using SUSTAIN model, for a 20 year return period, are presented in the following table.

Table 3 - Peak discharge obtained in SUSTAIN for current and future scenarios (T=20 years).

Control section	Peak Discharge (m ³ /s)		Section capacity (m ³ /s)
	2011	2051	
SP1	1.64	1.64	0.80
SP2	2.00	2.09	0.77
SP3	0.74	0.80	1.01
SP4	12.82	14.43	7.83
SP5	17.88	19.87	6.68

Although the results presented in table 3 are similar to those presented in table 1, there are some differences between the two models that can be explained by the following reasons: (i) stormwater runoff was generated in this study through nonlinear reservoir method, while in FEDMP, rational method was used to calculate this parameter; (ii) Imperviousness degree in FEDMP was estimated for the year 2006, while in this study this parameter was estimated using Bing Maps aerial imagery from July 2011.

As table 3 shows, zone 1 presents serious problems in stormwater drainage system, where only SP3 is able to drain stormwater runoff.

4 PLACING BEST MANAGEMENT PRACTICES ON THE FIELD

SUSTAIN allows users to place BMPs at strategic locations in urban watersheds using BMP sitting tool, which uses ArcGIS platform and user guided rules to determine site suitability for various BMP options (USEPA, 2009).

This study tested a combination of BMPs in order to solve/mitigate stormwater runoff problems existing in zone 1. This combination is formed by 3 BMPs, a Dry Pond (DP), a Wet Pond (WP) and an Infiltration Trench (IT), with the following objectives:

- The Dry Pond goal is to reduce stormwater runoff in section SP2 to 0.77 m³/s;
- The Wet Pond goal is to reduce stormwater runoff in section SP5 to 6.68 m³/s;
- The Infiltration Trench goal is to reduce stormwater runoff in section SP3 to 0.74 m³/s;

Optimization module of SUSTAIN was used to determine the minimum dimension of each BMP, and therefore the most economical solution, that can deliver the necessary reductions. The simulations were performed using the design storm hyetograph (T=20 yr), and for the post development situation (future scenario – 2051).

Generally speaking, this combination has been implemented to decrease stormwater runoff flowing into drainage systems and the goal is to reduce stormwater runoff to a limit that can be drained by the stormwater system. For areas that don't have problems (section SP3), BMP was designed and implemented so that the post-development

peak discharge (future scenario - 2051) conveyed to drainage system is the same as in pre-development situation (current scenario - 2011).

The total cost of the combination used in this study is estimated at 381071 €, and the BMPs have the following dimensions:

- **Dry Pond:** Length=34m; Width=55m; Height=0.5m;
- **Wet Pond:** Length=192m; Width=60m; Height=2.0m;
- **Infiltration Trench:** Length=175m; Width=1.20m; Height=2.0m

The following figures show the places where BMPs were implemented (figure 9) and the virtual stormwater drainage network model created in SUSTAIN with inclusion of the 3 BMPs (figure 10).



Figure 9 – Implementation of BMPs.

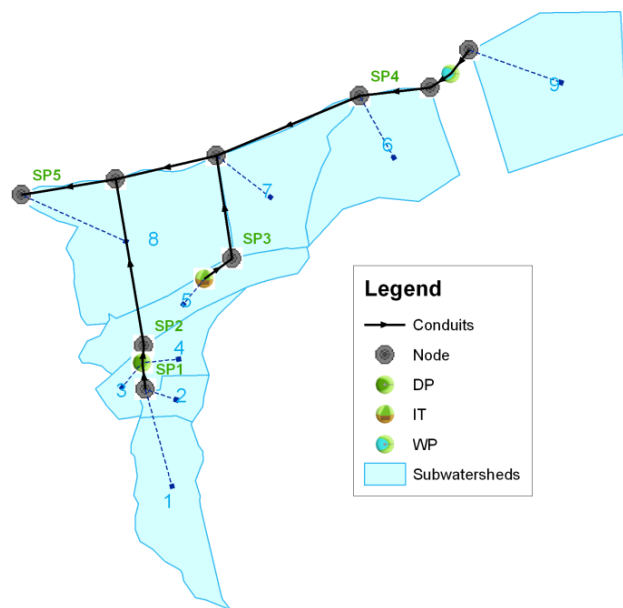


Figure 10 – Stormwater drainage network model with BMPs.

5 RESULTS

The results obtained with the implementation of BMPs described in the previous section are shown in table 4. As one can see, it is possible to solve stormwater drainage problems existing in 4 of the 5 control sections analysed in the present study. With regard to control section SP1, it is not possible to solve drainage problems existing in this section. This is due to the fact that the upstream area of this section is highly urbanized, which precludes the placement of a BMP in this area.

Table 4 - Peak discharged obtained in SUSTAIN with implementation of BMPs for current and future scenarios (T=20 years).

Control section	Peak Discharge (m ³ /s)		Section capacity (m ³ /s)
	2011	2051	
SP1	1.64	1.64	0.80
SP2	0.71	0.77	0.77
SP3	0.68	0.74	1.01
SP4	4.48	5.82	7.83
SP5	5.64	6.68	6.68

Regarding the efficiency of each BMP, the wet pond is the one that achieves the greatest performance, followed by the dry pond. Reduction efficiency achieved by three devices simultaneously in section SP5, for the two scenarios analysed, can be seen in figure 11.

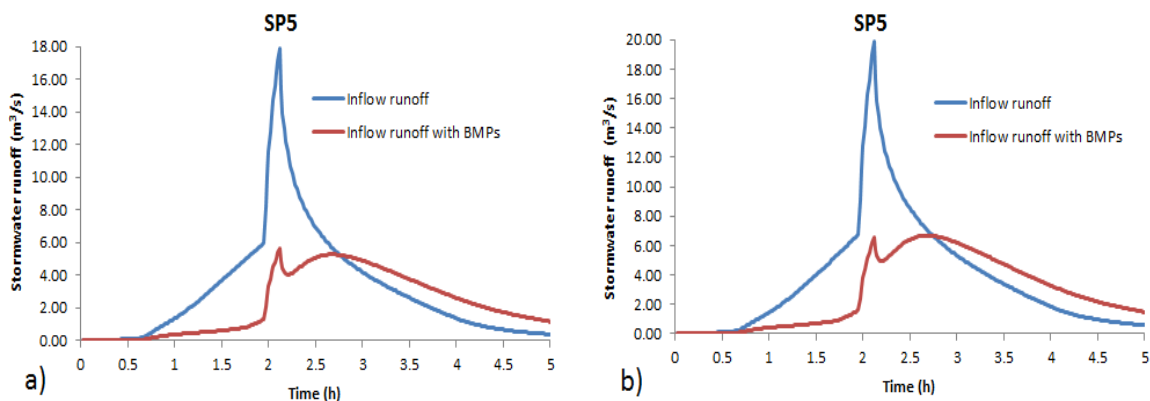


Figure 11 – Runoff hydrograph plot for the design storm event: a) Current scenario; b) Future scenario.

6 CONCLUSIONS

Good quality hydrologic and physical data are required to calibrate and test the parameters of hydrologic models. As cities expand and/or develop, hydrologic models will become outdated unless information on impervious surfaces is kept up to date. These models are of great importance in order to analyse urban drainage problems.

This study analysed the contribution of SUSTAIN as a decision support tool to solve problems of modern urban drainage existing in Fala-Espadaneira basin, caused by urban development. Impervious surfaces were identified and their boundaries digitized in order to develop a virtual stormwater drainage model for this basin. A combination of structural BMPs was implemented in the model in order to solve the problems identified for this catchment.

The results show that, despite the significant increase of the stormwater runoff, with the urbanization of the watershed, it is possible to solve/mitigate these problems using Low Impact Development techniques.

7 REFERENCES

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